Detectors

qutools

LASER COMPONENTS

quTAU

Time-to-Digital Converter

User Manual

Version 3.0

17.08.2012
qutools GmbH

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Technical Specifications

Parameter	Min	Max	Unit
Number of input channels		8	
Input pulse high level	2.4	5	V
Input pulse low level	0	0.8	V
Input pulse width	4		ns
Input pulse separation (same channel, typ.)	5.5		ns
Input impedance (choose either)	50	1000	Ω
Max. event rate (one channel, counting mode)		10	Mcps
Max. event rate (all channels, counting mode)		25	Mcps
Max. event rate (all channels, time tag mode)		3	Mcps
Bin width (least significant bit equivalent)	≈ 60	≈ 100	ps
USB interface	USB 2.0 high speed		
LAN interface	100 Mbit/s		
Digital GPIO interface	24 I/O signals, LVTTL		
Operating Systems	Windows XP, Vista, 7 Linux (current distributions)		
Power supply voltage	90	240	VAC
Power supply frequency	50	60	Hz
Power consumption		5	W
Power connector	IEC inlet		
Mechanical dimensions	23,5 x 9 x 31 (half 19", 2 HE)		cm
Weight	≈ 3		kg

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Changelog

Version 3.0 (August 17th, 2012)

- Firmware update! Please update the firmware with the (new) firmware update utility.
- Firmware update utility modified. Please use the new version only.
- The user DLL has been renamed to tdcbase.dll
- The daisy server (`daisysrv.exe`) is not used by the user lib (tdcbase.dll) anymore, it connects directly to the USB. This means that you cannot use the GUI (daisy) and the user lib (or multiple user lib clients) simultaneously.
- The channel numbers are 1 to 8 in all output data files.
- Installer: You can either use the installer or copy the content of the zip file where you want it.
- The GUI (daisy.exe) shows all available different histograms now, not only the channel independent one.
- Bug fix: The histograms are now calculated like start-stop measurements. Each event is used as a start (for that particular channel), but only as a stop, if there was no event on that channel in between.
- Histogram output from qutau.exe changed: The histograms between channels A and B are combined, B-A is the negative part, A-B the positive. The two "0" bins are added (see "known problems" below). Histograms A-A have not changed, there the negative bins are empty.
- The maximum event rate (through the user library) has been increased.

Hints, known limitations and problems

- Histogram bin "0": When the bin width of the histograms is 0, you can add the 0 bins of histogram A-B and B-A. When the bin width is greater than 1, the 0 bins will not be quite correct.

Version 2.0 (June 5th, 2012)

- The driver has been updated to increase the throughput. Please use the new one from our webpage (see below).
- The user DLL (now `qutaubase.dll`) has been redesigned and the documentation has been extended (see below).
- The Labview VIs have been redesigned to fit the user DLL.
- The command line interface (CLI) has been updated and now utilizes the user DLL.
- The coincidence counting for the first 4 channels is done in the device (so that the USB is not the bottleneck). For the coincidence counting it is assumed that looking at the last 4 time tags (only the first 4 channels are recalled here) is sufficient. This is true as long as there are never two events on the same channel within the coincidence time window.
- The counting mechanism (for single count rates) has been expanded to all 8 channels. The coincidences are still evaluated (inside the device) for the first 4 channels only.

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General Information

Bin width

The "width" of adjacent inherent time bins (of 81 ps) is not constant, but rather alternating. After each narrower one, there follows a wider one. This is a characteristic feature of the TDC chip in the device and can lead to effects like the time difference histogram shown in Figure 1.

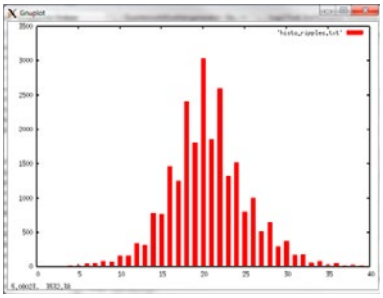

Figure 1: Time difference histogram with alternating population.

Time tags bit width

The internal size of time tags is 56 bit. They will overflow after $2^{56} - 1) \cdot 81\ ps = 5836665{,}12\ s = 67{,}55\ d.$

Necessary Software

Download the latest software package from our website: http://www.qutools.com/download/list.php

Linux support

The quTAU offers Linux support for current major distributions. Although this manual focuses on Windows users, most of the concepts are identical or very similar. If you have specific questions or problems using the quTAU with Linux, please contact us directly (see Some examples:

- To record time tags for 10 seconds as text to the file "textfile.txt" use
  `qutau.exe -t 10 -f textfile.txt`
- To record time tags for 100 seconds into a binary file "binfile.bin" use
  `qutau.exe -t 100 -F binfine.bin`
- To record time difference histograms for 20 seconds with bin width 1 and number of bins 5000 to the file "hist.txt" use
  qutau.exe –t 20 –H hist.txt –b 1 –B 5000
- To show the count rates with integration time 500 ms, coincidence window size 10 bins (10 times 81 ps), use
  `qutau.exe -C -e 500 -c 10`

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Installation

- connect the quTAU unit to a PC using a USB 2.0 cable
- connect the quTAU unit with a cattle plug to supply power
- switch on the quTAU
- Install the device driver
- Copy the software to a directory of choice (zip archive) or use the installer and follow its instructions.

Installation/ Update of the Device Driver (Windows)

When you first switch on the device on a specific PC, it will try to install the device driver automatically. Please use the current device driver from the software package (directory `usbdriver`). In case you are not sure or have an old version of the device driver, please update it using the following procedure.

You must be logged on as an administrator to perform these steps.

1. Open Device Manager by clicking the Start button, clicking Control Panel, clicking System and Maintenance, and then clicking Device Manager. If you are prompted for an administrator password or confirmation, type the password or provide confirmation.
2. In Device Manager (Figure 2), locate the device “N-Hands USB Device” in the section “USB Controller”, and then double-click on it.
3. Click the Driver tab, and then click Update Driver and follow the instructions. Use the driver from our website.

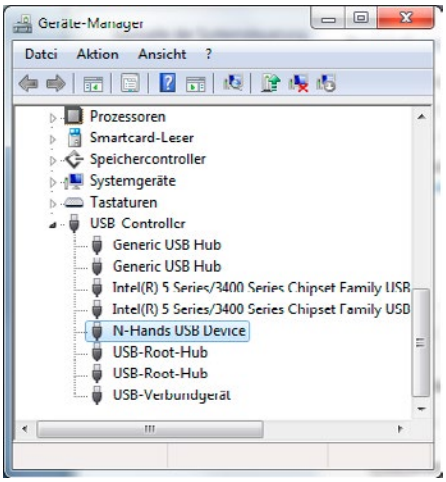

Figure 2: Device Manager for driver update

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Firmware Update

Attention: Naturally, firmware updates are a delicate process and can potentially damage the device if done incorrectly. This should be done only when it's advised to do so by the manufacturer. In this case, please read and follow these instructions carefully.

When a firmware update is required, please use the program `nhflash.exe` (Figure 3) in the main software directory or from the start menu to do so. You will find the current firmware in the directory "`firmware/`", there should be three files "`qutau_core.bit`", "`qutau_appl.bit`" and "`qutau_dsp.ldr`". They contain the firmware for the core FPGA (infrastructure), the application FPGA (handling the TDC chip) and the DSP of the quTAU device, respectively. The update utility checks on startup whether all three files are in place and will tell you if not. Please stick closely to the following steps:

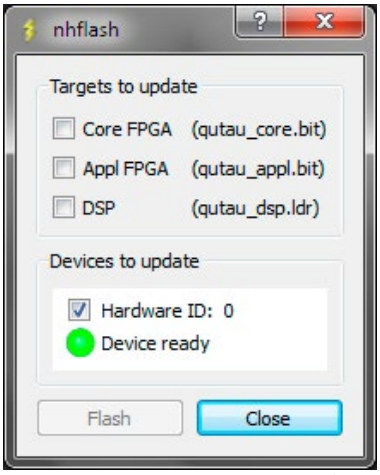

Figure 3: Firmware update software "nhflash.exe"

1. If the device is running, please switch it off.
2. If any quTAU software is still running, please close it.
3. Turn on the device.
4. Start "`nhflash.exe`" from the start menu or the main software directory. After some time the LED should get green and the text "Hardware ID: 0" (or similar) should be displayed (see Figure 3).
5. Select the firmware you want to update ("Targets to update"). You can select all at once, if you want.
6. If all of this is OK, please press "Flash". The green LED should start flashing until it is finished. At the end of the process, the LED should be green again and the text close to it should read "Update complete".
7. Press the button "Close". The firmware update utility is closed.
8. Turn the quTAU device off (and possibly on again). If you don't do this, the old firmware will still be in effect until the next restart.

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Software concept

The quTAU software concept is depicted in Figure 4. The device is connected via USB 2.0, so the first piece of software handling it on the PC side is the USB device driver. The device driver talks either directly to one (!) of the client programs. The clients are the native GUI client (“daisy”) or the user DLL (“tdcbase.dll”), the command line interface (“qutau.exe”), Labview™ VIs or other user written programs.

Daisy Server

The Daisy Server (`daisysrv.exe`) is invoked automatically by the GUI (daisy.exe). The user lib (tdcbase.dll) does not use the Daisy Server anymore. As a consequence of this, you can’t work with different clients (Daisy, command line interface, Labview VI) simultaneously anymore.

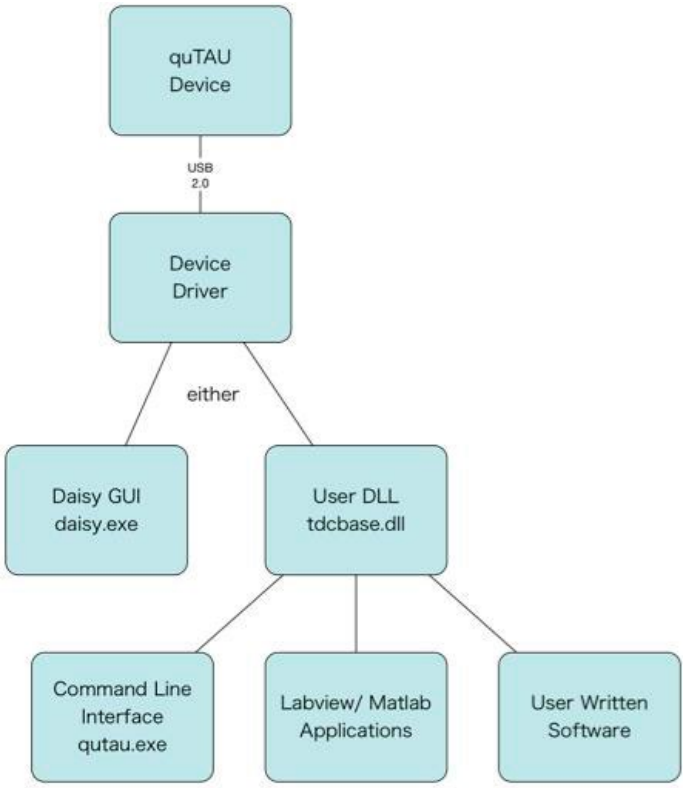

Figure 4: Software concept of the quTAU Time-to-Digital Converter.

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Graphical User Interface (GUI) `daisy.exe`

The quTAU comes with a native GUI (see Figure 5) `daisy.exe` that gives access to many features of the device. You can find it in the start menu or in the main software directory. Here, the most important functions are described.
When you start the GUI for the first time, the Windows firewall may ask you whether you want to allow the daisy server to open a port to the outside. This is usually unnecessary, so you can decline it.

Parameters (left-hand side)

1. "TDC Channel Enable": You can activate each of the 8 channels separately. Make sure, the ones you want to use are ticked.
2. "Coincidence Window": This value sets the half width of the coincidence window for the coincidence counting (see below) in generic TDC bins (≈ 81 ps).
3. "Exposure time": This value determines for how long the coincidence counters (see below) integrate until they get read out. The minimum is 1 ms.
4. "50 Ohm Input Term.": You can switch on or off the 50 Ohms input termination (for all channels together). If it is switched off, the signal is directly input to the TDC chip with about 1kOhms impedance.
5. "TDC Self Test": For testing, the quTAU can generate periodic signals and send them to the various input channels of the device. This feature can be controlled here. The general idea is that all channels do the same (apart from some intrinsic timing differences between the channels). There are always bursts of some signals, then there is a pause, then another burst comes.
    a. "Channel": Here you can set, which of the channels should be fired upon with self test signals.
    b. "Period": The time between signals inside a burst (minimum 40 ns).

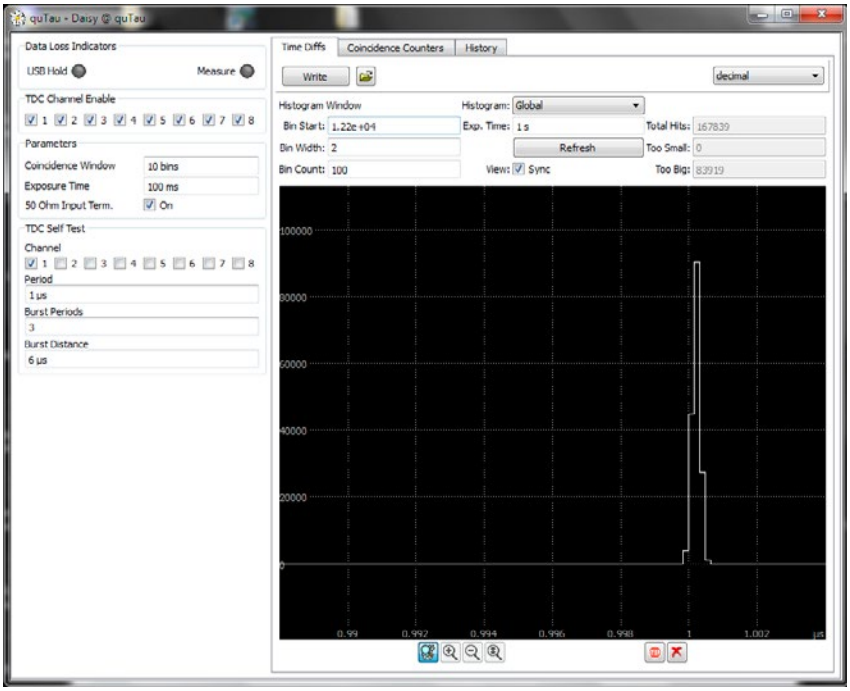

Figure 5: Graphical user interface (GUI) "Daisy" gives access to the main features of the device.

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c. “Burst Periods”: How many signals are inside a burst (minimum 1).
d. “Burst distance”: The period between two bursts (should be bigger than “Period” x “Burst Periods”).

Measurements (right-hand side)

Tab “Time Diffs”

6. “Write” button, file dialogue and format choice: With these controls you can record time tags to a text of binary file.
   a. Choose an output file using the button.
   b. Choose the format:
      - “decimal” means human readable time tags, first time tag, then channel number (from 1 to 8) separated by a comma.
      - “hex” the same in hexadecimal format,
      - “binary” in binary format, 8 bytes time tag, 2 bytes channel, Intel format (Little-Endian, lowest byte first).
   c. By hitting the “Write” button time tags are written into the specified file. Hit it again to make it stop.
7. Histogram and its settings: This window shows the current time difference histogram without regard to the input channel. You can set the update time by “Exp. Time”, Start and Width of the histogram etc.
   In the box “Histogram” you can select which of the histograms should be displayed. “Global” means that channels numbers are not regarded, “channels a – b” shows the histograms when channel a fired before b. All histograms are measured simultaneously.

Tab “Coincidence Counters”

Inside the device (not in the PC) there are some counters implemented that tell the user how many events there were during the last “Exposure Time” (6). The reason why this is already done in the device is that this way, one is not limited by USB to transfer the time tags to the PC. Hence higher count rates can be reached. Single count rates are measured for all 8 channels, only channels 1 to 4 have coincidence counting, too.

8. The bar chart shows the current count rates: First channel 1 to 8 (singles), then two-fold coincidences (events that occur within a time difference smaller than the “Coincidence Window” (5) between channels 1&2, 1&3, 1&4, 2&3, 2&4 etc., then 3-fold and 4-fold coincidences.

Tab “History”

9. The line chart shows the time evolution of one of the 19 counting channels (see 10).
10. You can choose the channel by this box.

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User DLL

The user DLL `tdcbase.dll`, (formerly `quTAU_wrapper.dll` and `qutaubase.dll`) can be used to interface customer specific software to the quTAU. It is used for the LabView connection (see below) as well as by the CLI (see before). The header file can be found in `inc/tdcbase.h` and the location of the DLL is in `userlib/lib/tdcbase.dll`.
The documentation (as a Doxygen report) can be found in `userlib/doc/index.html` or in the start menu.

LabView™

A Labview example (see Figure 6) can be found in `userlib/labviewXX/TDC_simple.vi` of the Windows package or in the start menu. If you need support for older Labview versions, please let us know. The Labview VIs are communicating with the device using the user DLL `tdcbase.dll` (see above). There are SubVIs for basically all exported functions by the user DLL. For documentation of the DLL functions, please see above.

Parameter settings (left-hand side)

On the left-hand side you can change some basic settings of the device like:

1. "Exposure Time [ms]": This is the integration time for the counters in ms. All experimental data (on the right) will be updated after this period.
2. "Input Termination": You can choose the termination of the input signals to be 50 Ohms or 1 kOhm. Using the wrong termination can course reflections and hence wrong results.
3. "Data loss" LED: If this gets red, the device could not transport enough time tags over the USB. Probably the event rate Is too high for the system to cope.
4. "Self test": In this case, the "Burst Periods" (i.e. the number of pulses in a burst) is fixed to 1, so that there will be a periodic signal with only two parameters left:
    a. "Channel Mask": Here, you can decide, which of the channels should be fired upon by the self test. It has to be set in binary, i.e. 0 means none, 1 is channel 1 only, 2 is channel 2 only, 3 channel 1+2 etc.
    b. "Burst distance": The period of time between two signals in multiples of 20 ns, minimum is 40 ns.
5. "Stop": Please always use this button to stop the VI, since then it can gracefully shut down the software.

Measurement area (right-hand side)

Tab "Counter"

6. "Coincidence Window [bins]": Sets the coincidence time window in bins (see above in the corresponding section of the GUI).
7. Line chart displaying the count rates of the first 4 single channels and all possible coincidence combinations (see above).
8. Array display on the right showing the values as numbers. The numbers are measured with respect to the exposure time (see 1).

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Tab "Histogram"

On this tab, you can see time difference histograms, calculated on the PC from the raw time tags. This is already one in the user DLL, so Labview™ only has to fetch and display it.

9. "Number of bins": How many bins should the histogram have.
10. "Bin width": How many (native = 81 ps) TDC bins should one histogram be. If this is set to e.g. 10, one histogram bin will be about 810 ps wide.
11. "Histogram reset": You can choose whether you want the histogram to be reset each time you read it out (i.e. after the "Exposure Time" (1) has elapsed) or not. If not, you see a cumulative histogram. You can choose this basically for all histograms separately.
12. "Reset all": If you want cumulative histograms, but reset them all at the same time, use this button.
13. "Histogram channel select": There are altogether 17 histograms calculated. The first one is channel independent, i.e. a histogram is made regardless of the channel number. The other ones are all channel dependent, from chanel 1 with channel 1, to channel 1 with channel 2 etc.
14. "Data Count": This number gives a total of events that have fallen into this histogram.
15. "Too small": The number of events that were too small to be used for the histogram (should be 0).
16. "Too large": The number of events that were too big to be shown in the

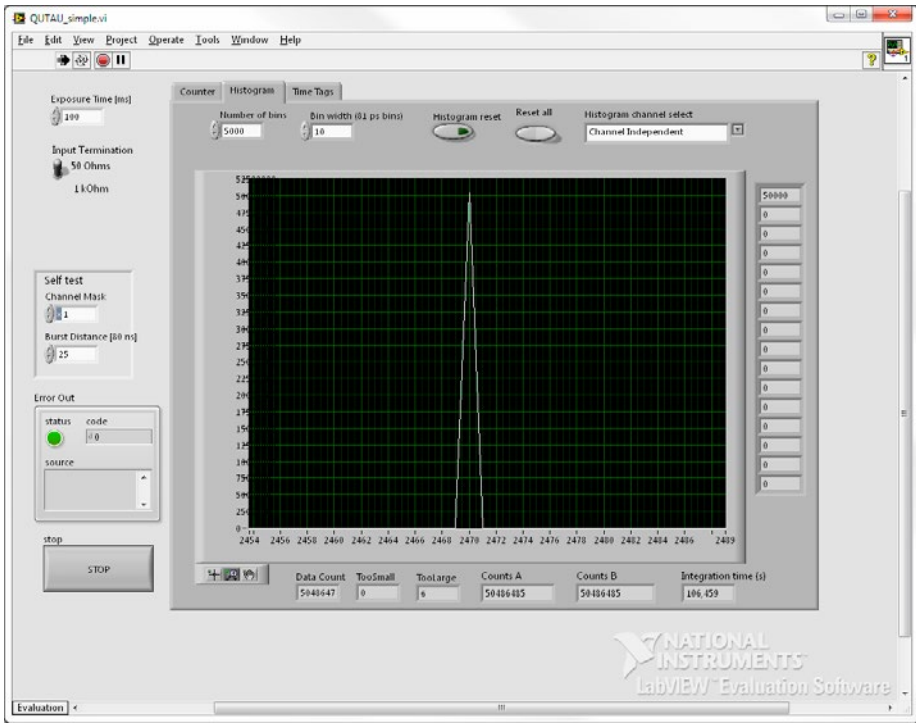

Figure 6: Labview VI example

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histogram (usually a large percentage of all events).

17. “Counts A”: The number of events from the first channel progressed for the histogram (not only those who actually fell in to a histogram bin). This should correspond to the count rate in the first channel. First channel means the first one mentioned in the histogram choice.
18. “Counts B”: Same as “Counts A” but for the second chosen channel.
19. “Integration time”: How long has the histogram been recorded (difference between last and first time tag used for the histogram). Displayed in seconds.

Tab “Time Tags”

On this tab you can see the time tags that are recorded by the user DLL.

20. On the left you see an array with the last time tags that have been fetched from the device.
21. The next column is the corresponding channel number (0 to 7).
22. The chart shows the time tags (time is on y-axis) against the array index.
23. “Buffer Size”: You can set the length of the array that is fetched in each turn. If it is too small or not fetched often enough (this is set by the “Exposure Time [ms]” control in the upper left corner of the VI), then some time tags will be lost due to full buffers (see LED “Buffer full”).
24. “Write to file”: Switch this on to write the time tags into a text file. The first column is the time tag in 81 ps units and the second column is the channel number. In between there is a tab.
25. “Binary format”: When this button is turned off, the output will be human readable text, first time tag in 81 ps units, then comma, blank and the channel number (from 1 to 8). When turned on, the output gets binary, first 8 bytes of time tag, then two bytes for the channel number (byte order Little-Endian).
26. “Path”: Open this dialog to specify the file path and name.

Please have a look at the documentation (`userlib/doc/index.html`) of the user DLL for further information.

Command Line Interface I (example0.exe)

The command line interface (CLI) is located in `daisybase/quTAU` and is called `example0(.exe)`. The sources can be found in the same directory. It uses the libraries in the same directory and communicates with the hardware via the `daisysrv` process. It needs the following DLLs (copy them from the main software directory):

- tdcaubase.dll
- nhconnect.dll
- QtCore4.dll
- QTGui4.dll

Call it by “`example0`” from a command line. It will take data for about 2 seconds and display some results:

- 50 time tags (in hex plus channel number)

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- The most recent internal counter values (channel 1..8, 2-fold coincidences (6), 3-fold coincidences (4), 4-fold coincidences (1) and all the rest (1).
- 2 time difference histograms, the channel independent one and the one between channels 1 and 2. The parameters for these are: Bin width 250 native bins, i.e. 20 ns, number of bins 40.

Command Line Interface II (qutau.exe)

The second command line interface (`userlib/source/qutau.exe`) has a few more features than the previous example. It is still intended as an example, but some basic tasks can already be fulfilled with it. The sources are included, too (`userlib/source/qutau_main.c`).

It uses the same libraries as the previous example (see above) and communicates with the hardware directly via USB. Hence, you can't use it simultaneously with other clients.

To start this CLI open a command prompt (via the Windows Start Menu or the shortcut Windows key + "r" and input "cmd"), go to the directory `userlib/source/` and call `qutau(.exe)`. Here are some of the parameters you can call it with to make it do what you want it to. Please also use the parameter "-h" for more information.

Parameter	Description
-h	Outputs help menu only.
-t <time in seconds>	The program records data for (at least) this time. Afterwards it closes itself and outputs the data as it has been told by other parameters.
-f <time tag file name>	All time tags are written to the given (text) file. The format is: "Absolute" time tag in native TDC bins (approx. 81 ps), blank, comma, blank, channel number (from 1 to 8). On exit the program may say "Time tag buffer was full [n] times […]". This means that the time tags were written into the buffer faster than they were read (at least partly). Some of the time tags in between may have been lost. Maybe using the binary writing function helps.
-F <binary time tag file name>	All time tags are written to the given binary file. The format is: 8 bytes of time tags in native TDC bins, 2 bytes for the channel number (0 to 7). Intel byte order (= Little-Endian, lowest bytes first).
-c <coincidence window in TDC bins>	Sets the coincidence window for the internal coincidence counters (first 4 channels) in native TDC bins (approx. 81 ps). Standard value is 100 bins, i.e. 8.1 ns.
-e <exposure time in ms>	Sets the exposure or integration time for the

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	internal counters (first 4 channels) in ms. The counters always count for this period. Standard value is 100 ms.
-C	Output the last counter values (to standard output) when the program terminates. They come out in the following order: Singles channel 1 to channel 8, 2-fold coincidences 1-2, 1-3, 1-4, 2-3, 2-4, 3-4, 3-fold coincidences 1-2-3, 1-2-4, 1-3-4, 2-3-4, f-fold coincidences 1-2-3-4. The integration time can be set with the –e option, standard is 100 ms.
-H <histogram file name>	Write histograms to text file. The output looks like this: First column is the bin number, second bin end time in ns. The next columns are the histograms between the different channels from 1-1, 1-2 to 1-8, 2-2 to 2-8 etc. until 8-8. The negative bins in columns "1-2" for example mean those events when first channel 2 registered an event, then channel 1, the positive vice versa. So the histograms 1-2 and 2-1, are combined. The values in those columns mean how many events have fallen into the time difference histogram bin. Standard values for bin width are 10 native TDC bins (i.e. 0.81 ns per bin) and 100 bins (i.e. a total of 81 ns for the whole histogram). These values can be changed using the following command line parameters. See also: Hints, known limitations and problems
-b <bin width in TDC bins>	Sets the bin width of the calculated histograms (see parameter –H) in native TDC bins (approx. 81 ps). So –b 10 means the histogram bin width will be 0.81 ns. This does not influence the time tags in case they are output. The maximum allowed is 100000. The standard value for this parameter is 10.
-B <bin count>	Set the total number of bins of the histograms. Standard value is 100. Maximum is 100000.
-S <channelmask>	Sets the self test channel bit mask. This can be used to test the TDC or the software. If the bitmask is 0, no events will appear at the input of the TDC. Otherwise the bitmask will determine which of the channels fire. 1 means channel one only, 2 channel 2 only, 3 channels 1+2, 4 channel 3 only etc. There will always be bursts of 2 (per channel), with

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	a delay of 80 ns, the time between two bursts is 20 µs (so we expect one peak at 80 ns, one at 19.92 µs and possibly one close to zero, when more than one self test channel is active). When this parameter is not set, it doesn't change the previous settings. So, you can e.g. set these values using the Daisy and they won't be changed, unless you use the parameter –S.

Some examples:

- To record time tags for 10 seconds as text to the file "textfile.txt" use
  `qutau.exe –t 10 –f textfile.txt`
- To record time tags for 100 seconds into a binary file "binfile.bin" use
  `qutau.exe –t 100 –F binfine.bin`
- To record time difference histograms for 20 seconds with bin width 1 and number of bins 5000 to the file "hist.txt" use
  qutau.exe –t 20 –H hist.txt –b 1 –B 5000
- To show the count rates with integration time 500 ms, coincidence window size 10 bins (10 times 81 ps), use
  `qutau.exe –C –e 500 –c 10`

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